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THE AERODYNAMIC HEATING PROBLEM

HYMAN H. ALBUM, 1st Lieutenant, USAF, Mechanics Division AFOSR

Recent findings by an AFOSR contract researcher have bearing upon the selection of materials for ablation cooling and the selection of gases for transpiration cooling. These cooling methods are in use, or are under consideration for reducing the severe heating associated with atmospheric flight of high-speed aircraft, space vehicles and missiles.

Missile designers have been neglecting an effect known as thermal diffusion in the theoretical equations for the prediction of heat transfer during the ablation process. Thermal diffusion accounts for differential movement of the molecules of one gas into another gas due to temperature variation.

Professor Judson R. Baron of MIT, who has been working under an AFOSR contract, has recently proved that thermal diffusion is significant, and must be considered in aerodynamic heating processes which involve the passage of a gas from a body into the airstream. Based on the old theory, which neglects thermal diffusion, many experimenters have been using helium forced through porous surfaces for cooling (transpiration cooling), because the lowest density gases were supposed to be the most effective. Professor Baron's new theoretical treatment and experimental results show that this is not necessarily true. Although air is considerably denser than helium, both air and helium produce an equivalent effect under flight conditions. He points out that when thermal diffusion is considered other previously observed discrepancies between theoretical predictions and experimental results can also be explained.

Professor Baron's results were presented to the American Rocket Society Space Flight Report to the Nation (ARS paper 2206-61) which took place in New York during October 1961. This work will be published as AFOSR report 1893.

TO OUR READERS

The continuing goal of the "OAR RESEARCH REVIEW" is an attempt to satisfy the information needs of both the scientist and the nonscientist decision maker, since we feel each is of importance.

It is inevitable that many decisions concerning basic research, from the budget that supports it to the manner in which it is fed into applied research and development activities, are made by people who are not scientists.

We believe that it is imperative that these people be informed about research in progress, and understand something of its potentialities. It is equally imperative that the scientist be kept up-to-date on research projects occurring within his areas of interest. Each time this publication prevents needless duplication of effort by informing a research scientist of new knowledge discovered, it will have achieved an important contribution to the conservation of the Free World's scientific resources.

Those of you among our readers who feel a need for further information about a topic covered in any issue are urged to contact the author or originating laboratory direct. Addresses for use on such occasions are shown on inside back cover of this issue.

Constructive criticism and suggestions for improvement will be most welcome, and should be directed to this headquarters, ATTN: RREI.

Daniel E. Hooks

DANIEL E. HOOKS
Major General, USAF
Commander

propagation anomaly

Propagation Sciences Laboratory, AFCRL

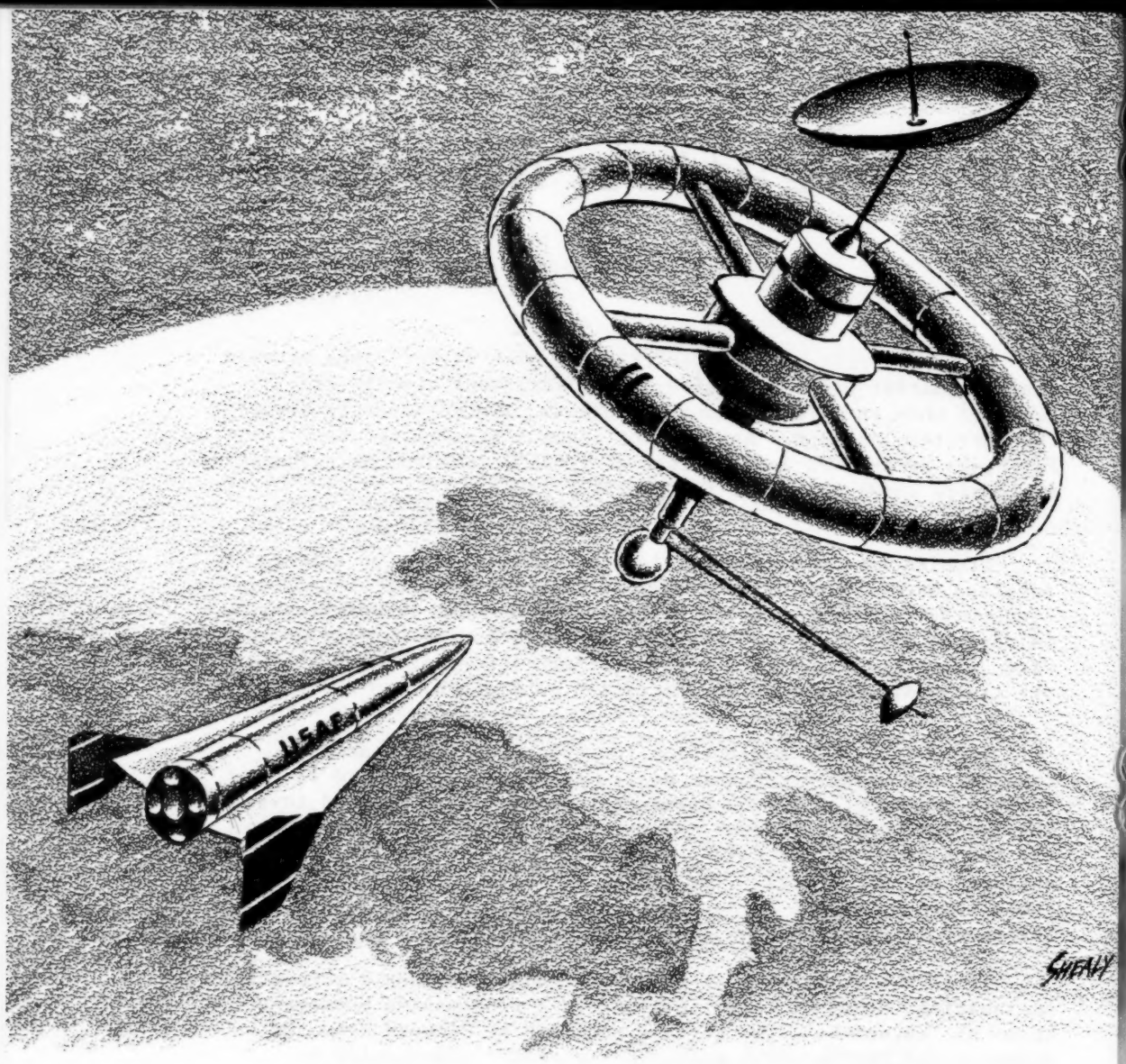
We expect radio signals to take the most direct route between the transmitter and the receiver. The strongest signals are received when the transmitting antenna is pointed directly toward the receiving antenna. Analysis of signals transmitted from Fairbanks at 18 MCPS and received at AFCRL's Concord, Massachusetts, field site shows that this isn't always true.

Studies of the Fairbanks signal, transmitted by an antenna rotating once a minute, have shown that the strongest signals are frequently received when the transmitting antenna is pointing some 15 degrees away from the Great Circle Route to the Concord antenna. Often the signals are much weaker, or are not received at all when the transmissions are in the direction of Concord.

The most likely explanation for this propagation anomaly involves the earth's magnetic pole. Reception at Concord is frequently strongest when the transmitting antenna is pointed toward the magnetic pole. Streams of ionization apparently travel down the force lines of the poles, presumably present vertical reflecting surfaces for the signal. The signal is reflected laterally from these ionized streams in much the same manner as signals are reflected laterally by the ionization of meteors.

It is not believed that this hypothesis provides a complete explanation, however. Also involved is a propagation phenomena known as "spread-F." The signals received at Concord from the direction of the magnetic pole are frequently accompanied by spread-F. This name derives from the fact that the signal is reflected from a variety of areas, and hence reaches the receiver at different time intervals.

This spread-F is known to have a stationary, permanent high located near the earth's magnetic pole. Hallock Marsh, who heads the AFCRL HF propagation research program, suggests the possibility that both the lateral reflections and the complex and little-understood spread-F mechanism are involved in the reception of the Fairbanks signals. AFCRL is now planning further experiments to confirm or deny this hypothesis, and to gain a broader understanding of ionospheric and propagation characteristics near the magnetic pole.



ARL CONTRIBUTIONS in ASTRODYNAMICS

DR. CARL A. TRAENKLE, Applied Mathematics Br. ARL

The possible advent of manned space stations circling the earth as satellites has raised many interesting problems.The primary one is concerned with the maintenance and supply of the station,which implies the setting up of ferry operations between the earth and an orbiting satellite.An interesting paper,"Layout

of Satellite Ferry Operation" (Z.Flugwiss,Vol.9,1961,pp 334-341), has been written recently by Dr.Carl A. Traenkle of ARL.A number of other problems have been analyzed and elaborated which are applicable to more general problems in Astrodynamics.

Usually,it is assumed that the earth satellite,or in our case,the space station,is moving in a circular orbit around the earth center,at an arbitrary inclination angle with reference to the equitorial plane,covering the complete range from polar to equitorial orbits.In a first step,the ferry vehicle is launched from a launch site on the surface of the rotating earth into a preliminary orbit just above the appreciable earth atmosphere and coplanar with the station orbit,the so called "ground orbit".From here,the ferry is fired at the appropriate instant in tangential direction into a "Hohmann" transfer ellipse (an ellipse tangent at the extremities of its major axes to both orbits),transferring it to the station orbit at minimum energy expense.

The transfer of the vehicle must meet special conditions expressed by the characteristic parameters of the process.First,at the appropriate instant,the vehicle is injected into the Hohmann ellipse by a first tangential velocity kick.In reaching the station orbit at the rendezvous point (point of coincidence),the vehicle is being overtaken by the faster moving station,approaching from behind;at this instant,the vehicle has to be synchronized with the station by a second tangential velocity kick.The velocity parameters, as well as the other characteristic parameters,can be computed by the well known Keplerian laws of planetary motion and their corollaries.In the case of the velocity kicks,the computation is performed by means of the vis viva and area theorems.Both velocity kicks are added up to form the so called "velocity sum" which is characteristic for the performance and size of the required rocket motor.The velocity sum can be represented as a function of the ratio of the radii of station and ground orbits,the so called distance ratio;it shows a maximum at a distance ratio of about 18.The condition that vehicle and station meet at the point of orbital coincidence is equivalent to injecting the vehicle at an exactly determined instant from the ground orbit into transfer trajectory.This instant is defined by the configuration of station, earth center and vehicle-in other words,by the angle between the earth center-station ray and the earth center-vehicle ray,the so called lead angle.This lead angle can be calculated by a time proportion taking into consideration the transfer time of the vehicle and the period of the station.It can also be represented as a function of the distance ratio.An instant favorable for injection is reached each time the vehicle in ground orbit passes the lead angle ray.This instant recurs periodically with the recurrence period,defined by the relative motion of the vehicle ray with respect to the station ray.The recurrence period is identical

with the "synodic" period of the ground to station orbit system. The relations between all these quantities are expressed in dimensionless parameters and represented in graphs for a wide range of application.

By a possible error accumulation in the injection process,it may happen that the vehicle arrives at the target orbit either ahead of or behind the station.In other words,there may remain a certain constant miss angle between vehicle and station because the vehicle has the same period as the station after it has been injected and synchronized in the station orbit.This residual error can be eliminated by two alternate correction maneuvers;the full cycle correction,and the short arc correction.In the first method, the vehicle is temporarily injected by a tangential velocity kick into a slightly different orbit tangent to the original station orbit at the point of maneuver initiation.The vehicle travels along the new orbit for a full cycle or generally for an integral number of full cycles.The period of the new orbit differs from the original orbit as required by Kepler's third law.Therefore,upon return to the starting point,it is possible to reduce the original miss angle to zero,if the velocity has been adjusted appropriately. For example,if the station is ahead of the vehicle,one has to apply a retarding velocity to the vehicle,which seems paradoxical at first.However,the vehicle will appear earlier at the coincidence point after completion of its correction cycle,and the adjustment can be made just big enough to compensate for the original deviation.When the original miss angle is small enough,it seems more natural to correct this condition by direct action without going through full orbit cycles.Here,the second method,the short arc is applied.If the station is ahead of the vehicle,the latter will be accelerated to catch up with the station.The mechanics of this process show that the corrective velocity kick no longer must be applied tangentially,but at a certain inclination toward the earth center.In this way the station orbit is undercut and the station itself overtaken.With the appropriate velocity correction the two bodies will meet when the correction trajectory intersects the original orbit.If the miss angle has the reversed sign,all significant quantities of the process reverse sign correspondingly.The characteristic parameters of both correction methods are analyzed in detail and represented in graphs and charts. The comparison of the methods shows that the first is especially favorable with respect to small velocity corrections and,therefore, to fuel economy.The second is advantageous with respect to short maneuver duration,but it should only be applied for very small miss angles because of the much higher fuel consumption.

The results of this paper for circular orbits can be generalized for elliptic orbits.The approach,employed here,has served as a guide-line in solving this problem.A paper on this topic is in print.

MAGNETOGASDYNAMICS

MILTON ROGERS, Mechanics Division, AFOSR

Since the pioneering work by Hartmann and Lazarus in 1937, the theory of viscous hydromagnetic channel flows has been brought to a state of considerable refinement. Very little progress has, on the contrary, been made on the problem of extending this theory to the case of compressible flow. One reason for this is that the problem of ordinary gasdynamic flow of a viscous fluid in a constant-area channel or between parallel walls does not have a simple solution. Yet, the extension of hydromagnetic-channel theory to the case of compressible flows has great theoretical interest, and also some practical applicability in view of the recent interest in magnetogasdynamic channels for gas acceleration and power generation.

Under AFOSR sponsorship, a group working under Dr. W. R. Sears at Cornell University is studying the general problem of magnetogasdynamic flows. A recent report, AFOSR 1332, presents the results of a thorough analytical development by Dr. Sonnerup of the "Theory of Viscous Magnetogasdynamic Flow in Slowly Diverging Two-Dimensional Channels." Dr. Sonnerup was awarded the 1961 American Rocket Society Thiokol Graduate Student Award ($1,000) for this work.

Although the choice of a diverging channel was made for mathematical convenience in order to circumvent the profusion of analysis normally associated with the problem of viscous compressible flow between parallel walls, it should be noted that the diverging generator channel is also desirable from a practical point of view. In this study, the conducting walls of the channel served as electrodes, and were connected to an external load so that the device operated as a power generator. The main component of the applied magnetic field was perpendicular to the flow direction but parallel to the channel walls. The flowing medium was a slightly ionized gas with variable fluid properties. In particular, two different mathematical models of the electrical conductivity were used. The theory pertains to low values of the magnetic Reynolds number, based on the channel height, and to moderate values of the Hall parameter. Entrance and exit effects were not considered.

The equations of fluid dynamics were simplified by approximations similar to those employed in ordinary boundary-layer theory, and the resulting set of equations was then solved exactly and in closed form for a particular family of pressure variations along the channel. The main parameters appearing in the solution are the viscous Reynolds number, the Mach number, the Hartmann number and a parameter describing the pressure variation along the channel.

Mach 10–17 Pilot Tunnel Design and Performance

WALTER W. WELLS, Captain, USAF, Hypersonic Research Branch, ARL

The effects of air moving at hypersonic speeds are being studied in the 3-inch hypersonic wind tunnel (3" HWT) located at the Aeronautical Research Laboratory, Wright-Patterson Air Force Base, Dayton, Ohio.

This 3-inch hypersonic wind tunnel is being utilized to conduct the experimental portion of fundamental research studies at ARL. These basic research studies are centered around the testing of simple model shapes (i.e., cones, cylinders, spheres, and wedges) to determine the effect that these shapes have on the hypersonic stream. This effort is fundamental research, as contrasted to engineering testing being accomplished at other facilities where the objective is the determination of the performance of missiles and aircraft at hypervelocity conditions. ARL's fundamental work will form the basis for future engineering in the broad aerospace field.

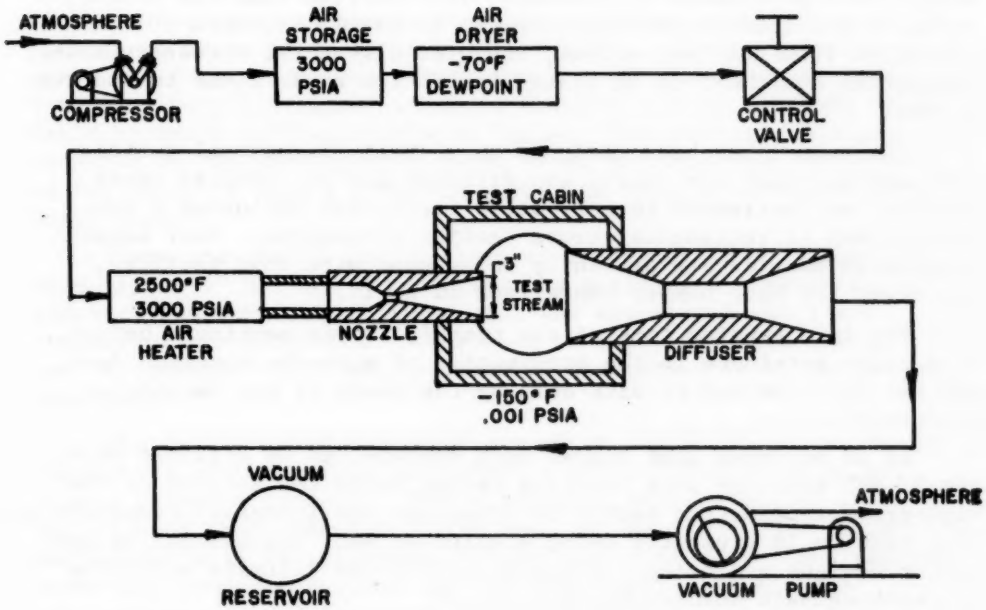
Over the past few years, the Air Force Aeronautical Research Laboratory, aided by the Ohio State University and Systems Research Laboratories, Inc., of Dayton, Ohio, has developed and instrumented this particular 3-inch hypersonic wind tunnel for a capability of operation at gas speeds up to 17 times the speed of sound, Mach 17, for continuous periods up to four hours. The long running time at this high Mach number is not only unusual for a hypervelocity wind tunnel, but is very necessary to obtain the experimental pressure and temperature data common to basic research in gas dynamics.

The 3" HWT gets its name, as do most hypersonic facilities, from the size or diameter of the wind tunnel nozzle exit. In this facility, the diameter is three inches. The designation is made because this diameter determines the size of the hypersonic test stream, and thus forms the basis of experimentation with respect to model and probe size. The attached diagram shows a schematic of the 3" HWT.

The schematic shows atmospheric air entering the compressor where its pressure is raised to 3000 psia and fed into the air dryer where entrained moisture is removed. From the dryer, the air passes through the stagnation control valve and into the electric heater where the high pressure air is heated to as high as 2500°F. (The drying and heating steps are necessary in hypersonic tunnels

to eliminate a detrimental phenomenon known as air liquefaction. This phenomenon does not occur in hypersonic space flight, and must be negated in atmospheric experimental work so that close correlatable data can be acquired.) The dry heated high pressure air now enters the nozzle where it expands, and becomes a high velocity stream or jet in the test cabin.

AERONAUTICAL RESEARCH LABORATORY
3 INCH HYPERSONIC WIND TUNNEL SCHEMATIC



This high-speed jet of air molecules now becomes a flow field in which the basic characteristics of the hypersonic gas can be observed. The nozzle has changed the slow moving, high temperature, high pressure air into a hypersonic speed, low temperature, ultra low pressure stream of air molecules. The vacuum-tight test cabin which surrounds this jet has thick glass ports through which visible data and shock formation photographs may be had. Instrumented models or probes may be inserted through the top of the test cabin, so that the basic high-velocity temperature and pressure data can be acquired. This data can then be "digested" by a computer and transformed into a final language from which the ARL scientist deduces or proves his theoretical findings.

The remainder of the schematic shows the high-speed air jet

passing through the diffuser where its velocity is transformed into higher pressure along with a recovery to near room temperature. From here, the air passes into the vacuum sphere or reservoir and through the vacuum pump where it is exhausted to the atmosphere. This latter step insures that the necessary pressure ratio is maintained across the wind tunnel, and is produced by applying a high pressure at the entrance and vacuum to the exit of the nozzle.

The 3" HWT at ARL has several unique design features which enhance its operation and add to its versatility.

The 3" HWT facility utilizes an open jet test cabin in which the 3" diameter hypersonic test jet is allowed to flow from the nozzle to the diffuser unconfined. This insures that the models, probes and allied instrumentation can be easily injected or retracted from the test stream, and also allows the necessary model supporting equipment to be placed inside the cabin close to the test stream.

The tunnel has been designed as a three-dimensional tunnel. This implies that the nozzle and diffuser are of circular cross section, as contrasted to many other facilities employing a two-dimensional or rectangular cross section throughout. Four interchangeable nozzles are presently being used with this facility, and cover the Mach number range from 10 to 17.

The long running time of the tunnel, as was mentioned before, is a prime attribute in the acquisition of accurate research data, and has been limited to date only by the needs of any particular experiment.

It is believed that higher Mach numbers can be attained using the 3" HWT with the only limiting factor being the ability of the high-pressure electric heater to withstand the increased temperatures. This problem is presently being studied at ARL, and several unique heater designs are being contemplated with the ultimate objective of reaching Mach numbers approaching 30.

In regard to acquiring accurate data, a basic language of research, instrumentation plays a vital and indisputed role. The instrumentation associated with the 3" HWT is no exception to this rule. The visual data which has been acquired in this tunnel centers around the observation and recording of shock wave and boundary layer phenomena occurring at the aforementioned high Mach numbers. The shock waves associated with a model in a hypersonic gas flow field, when viewed by suitable photographic methods, take on the appearance of the two-dimensional case of a boat traveling through still water. A clearly discernible bow wave from the boat would be similar to the bow shock wave associated with a model in hypersonic flow. The turbulent wake behind the boat is closely analogous to that wake behind the model in hypervelocity flow. By viewing the hypersonic shock waves and boundary layers of several basic models placed in the 3" HWT, it becomes apparent that some shapes, for

example, absorb much more heat from the flow than do others. These experimental tests proved the mathematical heat transfer theory previously formulated. The point here is, that only through the observation of the shock waves and boundary layers and temperature determination on the surface of the model by the use of thermocouples was it possible to prove the theory and, in many instances, modify and correct the mathematical approach. In the above instance, the visible observations were recorded using the Schlieren Photographic Camera. The temperatures on the model surface were recorded from the thermocouples on an oscillograph. Another instrumentation approach used quite often in the 3" HWT is the determination of pressures on the surface of models. These pressure surveys are conducted by drilling numerous holes or orifices at right angles to the model surface, and by attaching pressure transducers or pickups to these orifices by means of tubes. These transducers sense the local model pressures, and convert the pressure level into an electrical signal which is brought through the test cabin walls by means of insulated wire leads. This electrical signal is recorded on the photographic paper of an oscillograph, or it can be fed directly into a computer where the data is converted into final form.

These are just a few of the many instrumentation techniques used in the 3" HWT for determining the basic data parameters of pressure and temperature along with the associated shock and boundary layer phenomena. It should be mentioned that the accurate acquisition of these fundamental quantities is of paramount importance.

The 3-inch hypersonic wind tunnel at the Aeronautical Research Laboratory will continue to support a heavy schedule of experimental research testing. From a facility standpoint, it is anticipated that sometime in the near future the 3" HWT operational Mach range will be increased. It is also planned to test improved pressure, temperature, and optical instrumentation systems particularly suited for these higher hypersonic velocities. A present study is under way to determine the feasibility of electrically charging a high-voltage model in the test stream and photographing the resulting spark discharge to the hypersonic stream. It is believed that this "corona effect" or high-voltage discharge which closely follows the shock and boundary layer formation around a model in the test flow will greatly enhance the ability to visually observe and photograph these optical phenomena.

This combined fundamental study in instrumentation and gas dynamics serves to illustrate one of many research projects that are presently being carried out at ARL in the 3" HWT. Future studies will further exemplify the imaginative and creative abilities of the research staff at the Aeronautical Research Laboratory.

WITS and WITTICISMS in STRESSFUL SITUATIONS or KEEPING YOUR WITS ABOUT YOU

H. J. SANDER, Behavioral Sciences Division, AFOSR

One does not need to be a philosopher or psychologist to recognize the value of a sense of humor to anyone involved in a frustrating situation or coping with a difficult personal problem. In fact, one of the most striking indicators of mental illness is a complete lack of humor.

It has also been noted in case records that the wit or "funny guy" can frequently relieve tension, raise morale, and increase efficiency of a group or unit in a stressful situation by his humorous or sarcastic remarks. Reports of the behavior of military units in combat, survival and captivity situations contain many references to the tension reducing effects of witty remarks of such people.

Despite the large body of scientific literature on stress, however, there has been a peculiar dearth of empirical and theoretical research on the function of humor and the role of the wit in groups under stress. Doctor Ewart E. Smith of The Matrix Corporation, under contract with AFOSR, has accordingly been engaged in investigating the role of the wit in small groups under stress. He has begun with a series of field studies in which groups under various types of stress are being observed, tests administered and methods worked out for identifying wits and assessing their effects upon the group.

When this was done, it was found that the deliberate wit consistently emerged as a more active, self-confident individual. His activity was revealed in his high over-all participation in the group. His self-confidence was indicated by appropriate test results and his obvious lack of a defensive attitude under stress. Greater independence of thought of the deliberate wit was seen from the fact that he changed solutions less frequently following group discussion in order to conform to group solutions than did others.

As to the probable effect of the wit on the group, investigations to date indicate that the deliberate wit is present in groups whose morale and efficiency are significantly higher under stress than exists in other groups. Apparently, joking behavior has a complicated relationship to stress. Witticisms can either be used by those who are committed to their use as an interactional technique to reduce the tensions of a group under stress, or wit-

ticisms can occur as a natural result of stress and serve as an indicator of tension.

In summary, results of investigations to date indicate that individuals who have been identified as deliberate wits are able to use witticisms to reduce the effects of stress on their groups and exhibit the characteristics generally associated with leadership. The investigator has not yet studied the content of these witticisms to determine the exact mechanisms used and how these witticisms differ from those which occur at random in groups under stress without apparent positive effect. This will be the next step in this research, as it continues with field studies of comparative isolated and nonisolated Air Force operational units.

LUNAR DUST:

Compact or Treacherously Soft?

Research Instrumentation Laboratory, AFCRL

The problem of dust on the moon's surface, and how the Air Force plans to find out if the dust will hamper explorations on the moon, has been under study at AFCRL for several years. Much of the AFCRL work is carried out under the direction of Lieutenant J. W. Salisbury (Ph.D.) who recently reported on the current status of our knowledge of the moon's surface.

Current thinking on the dust problem is divided into two main camps. One group feels that the surface dust is deep, treacherously soft and yielding. They feel the loose dust has been caused by

electrostatic repulsion of dust particles charged by the bombardment of solar radiation. In other words, the dust is put into suspension by static electricity. If such is the case, then this dust layer will seriously hamper explorations by both men and machines on the face of the moon.

The second group feels that moon dust is thin, compact and unyielding. They believe that the almost perfect vacuum on the moon would not permit dust particles to be slightly separated by air molecules as they are on earth. This they say would result in a tightly packed, firm surface. They say too, molecules of surface material sputtered off of nearby grains by the impact of solar protons and neutrons tend to act as a cementing plaster on the dust. If this is the case, then moon surface explorations will have one less handicap.

Most estimates of the dust's depth and density have been made by analysis of the moon's infrared radiation. The change in temperature of the lunar surface during the lunar day determined in this way is a function of the heat applied by the sun and the thermal conductivity, density, and specific heat of the lunar surface materials.

Previous researchers have assumed that the thermal properties and density of the surface materials remained constant, even though the moon's surface heat changed during the day. On the basis of temperatures observed, they developed models of the lunar surface bearing appropriate thermal properties and density.

Dr. Salisbury has suggested that, if the lunar dust is loosened by the charging effects of solar radiation, the degree of looseness should change as the intensity of sunlight changes during the lunar day and, as a result, both thermal conductivity and density will be variable. Unfortunately, our measurements of lunar temperatures are so crude that these effects would not be detectable using present techniques.

Main obstacle to better measurements is the earth's atmosphere. To help overcome that handicap, Boston's Tufts University is building a balloon-borne telescope for the Cambridge Research Laboratories. It is part of a balloon astronomy program initiated by AFCRL.

Another AFCRL scientist, Roger A. Van Tassel, is developing a technique for determining lunar temperatures, especially the very low temperatures, by using an interferometer. This device is used to determine the amount of heat energy released by the moon at various wave lengths of the infrared spectrum. The shape of this energy curve is a more accurate indication of temperature than any other method now in use.

Through these efforts, AFCRL hopes to have answers to many questions on lunar surface conditions within a year's time.

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